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ABSTRACT

In recent years, there has been a growing interest in the knowledge base of prospective science teachers. An important part of their pedagogical content knowledge (PCK) consists of concerns about teaching. Most of the research on these concerns is focused on rather general teaching issues, and little is known about their concerns dealing with teaching specific science issues. This paper presents an exploratory study of prospective teachers' concerns about teaching a central issue in science: linking macroscopic phenomena with microscopic particles and symbolic representations such as formulas and equations. Teaching this issue evokes a lot of students' conceptual difficulties, and for that reason, may evoke pedagogical content concerns (PCC) among prospective teachers. In this naturalistic case study, prospective teachers (n=8) were interviewed before and after the first two weeks of lessons about relevant topics at a macro-micro symbolic interface. The semi-structured interviews and the lessons were audiotaped and analyzed. The results reveal a number of important characteristics of the nature of the development of prospective science teachers' PCC. Implications of the study for science teacher education are discussed. Contains 30 references. (Author/WRM)

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Prospective teachers' concerns about teaching chemistry topics at a macro-micro-symbolic interface

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The macro-micro-symbolic interface

Macroscopic domain
(substances, phenomena, etc.)

Symbolic representations
(formulas, equations, etc.)

Microscopic domain
(molecules, atoms, etc.)

Abstract

In recent years, there has been a growing interest in the knowledge base of prospective science teachers. An important part of their pedagogical content knowledge (PCK) consists of concerns about teaching. Most of the research on these concerns is focused on rather general teaching issues. Little is known about their concerns dealing with teaching specific science issues.
This paper presents an exploratory study of prospective teachers' concerns about teaching a central issue in science education: i.g. linking macroscopic phenomena with microscopic particles and symbolic representations such as formulas and equations. Teaching this issue evokes a lot of students' conceptual difficulties, and for that reason, may evoke pedagogical content concerns (PCC) among prospective teachers.
The research was designed as a naturalistic case-study. Eight prospective teachers (all M. Sc.) were interviewed before and after the first two lessons about relevant topics at a macro-micro-symbolic interface. The semi-structured interviews and the lessons were audiotaped and analysed. The results reveal a number of important characteristics of the nature of the development of prospective science teachers' PCC. Implications of the study for science teacher preparation courses are discussed.

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1. Introduction

In recent years, researchers have shown a growing interest in the conceptions of science teachers about the teaching and learning of science (Anderson and Mitchener, 1994). This development has been stimulated by the growing notion that there is a strong relationship between what teachers think and how they teach. As Clark and Peterson (1986) have pointed out, this relationship has a reciprocal characteristic: teachers' conceptions affect their planning and classroom decisions, while conversely their teaching activities influence their conceptions.
In the field of science teacher preparation, the interest in the required knowledge base of prospective teachers is particularly promoted by the awareness that the study of an academic discipline may not provide them with the kind of understanding prospective science teachers need to effectively transform their academic knowledge into instructional activities in the classroom (Sanford, 1988). This transformation problem causes a lot of concerns for prospective science teachers. Many prospective teachers do not understand well what they need to learn. They can only learn by gaining experience with it.
Most of the studies of prospective teachers' concerns deal with rather general issues, such as concerns about the development of self-image as a teacher (Kagan, 1992), concerns about workplace constraints (Clandinin, 1989) and concerns about socialization into the profession (Veenman, 1984). Only a small amount of research is focused on concerns about science teaching, such as concerns about the nature of science teaching (Bryan and Abell, 1999), about the perceived importance of science in the school curriculum (Appleton and Kindt, 1999) and about science curriculum development (Adams and Krockover, 1997). However, little is known about concerns dealing with teaching specific science curriculum content, although the interest in these kind of concerns is beginning to grow (De Jong et al, 1999).
In this study, the science- content related concerns was explored among a group of prospective chemistry teachers. The purpose of this study was twofold. From a theoretical point of view, we aim at contributing to a better understanding of the nature of prospective science teachers' concerns about science issues. From a practical point of view, the results will have implications for the design of science teacher preparation courses.

2. Background of the study

2.1 Concerns of prospective teachers

In connection with the knowledge base of prospective teachers, Shulman (1986) has introduced the concept of pedagogical content knowledge (PCK) to acknowledge the importance of the transformation of subject matter knowledge *per se* into "subject matter knowledge *for teaching*" (Shulman, 1986, p. 9). For prospective teachers, the subject matter knowledge acquired during their science studies constitutes one of the main bases from wich their PCK may be derived. Gess-Newsome and Lederman (1993) have noted that the subject matter structure of prospective science teachers is often vague and fragmented at the start of their teacher education program. By getting acquainted with the specific conceptions and ways of reasoning of students, prospective teachers may start to restructure their subject matter knowledge into a form that enables the productive communication with their students (Lederman et al., 1994). However, the development of PCK seemed to be

hindered by the complexity of the teaching practice (Gess-Newsome and Lederman, 1993).
The prospective teachers' knowledge base plays an important role during the preparation, implementation and evaluation of the lessons. These activities also contribute to a growing awareness of obstacles in teaching, in other words, to the development of teacher concerns.
From research on concerns of both prospective and beginning teachers, Fuller and Bown (1975) have described a cluster *model of concerns* including the description of changes in the nature of teacher concerns as stages in the professional development of teachers. According to their somewhat tentative model, the first stage contains concerns on issues such as the self-image and ways to survive in the classroom: self concerns. Prospective teachers have more concerns of this type than beginning teachers. The second stage contains concerns about issues such as teaching performance and adequacy of content knowledge: task concerns. Beginning teachers have more concerns of this type than prospective teachers. The third stage contains concerns about issues such as understanding students and their learning processes: student concerns. Although this type of concern is expressed by both prospective and beginning teachers, the prospective teachers feel themselves to be more unable to act on these concerns.

Reviews of later research on the concerns of both prospective and beginning teachers of several disciplines has confirmed the stage model. (Veenman, 1984; Kagan, 1992). For example, Veenman (1984) has identified as follows the most common problems, mentioned by beginning teachers of different disciplines (in descending order): concerns about classroom discipline, motivating students, dealing with individual differences among students, assessing students' work, relationships with parents, organization of class work, insufficient materials and supplies, and dealing with problems of individual students. This list also shows that it is not so easy to link a particular problem with a particular stage of Fuller and Bown's model. Some reported concerns can be put into more than one stage. For example, motivating students can belong partly to self concern and partly to task concern.
Both reviews hardly include any studies of concerns of prospective or beginning teachers of science. Recently, some such studies have been reported. For example, Adams and Krockover (1997) investigated the concerns of eleven beginning secondary science (and mathematics) teachers. They found concerns about (in descending order) time management, discipline/classroom management, curriculum development, presentation of content and class responsibilities. Appleton and Kindt (1999) investigated the struggles experienced by nine beginning primary science teachers as they tried to address the teaching of science in their classrooms. They reported concerns about (in descending order) lack of self-confidence, lack of collegial support, lack of resources and the low priority given to science by the school system. The results of both studies are in line with the findings of the reviews. That means, in general, prospective or beginning science teachers express more or less the same concerns as teachers of other disciplines. However, both studies, just as the other studies mentioned before, hardly give specific information about concerns on how to teach particular curriculum topics and issues. research on such concerns, which we will call *pedagogical content concern (PCC)* as a part of PCK, has hardly been carried out.

2.2 The macro-micro-symbolic interface

The present study focuses on prospective teachers' PCC about a central issue in science education, viz. teaching and learing the relationship between the macroscopic domain and the microscopic domain. The macro-domain mainly deals with substances and their properties, science processes and phenomena. The micro-domain mainly deals with corpuscular models, such as molecules, atoms and ions. At the macro-micro-interface, representations play an important role. Several kinds of representations are usual, such as icons, diagrams and symbols. In the present study, the macro-micro-interface will be mainly elaborated for just *symbolic representations*, such as formulas and equations (Figure 1). Moreover, the present study will deal with that interface in the context of chemistry (teacher) education only.

Figure 1 The macro-micro-symbolic interface

Macroscopic domain
(substances, phenomena, etc.)

Symbolic representations
(formulas, equations, etc.)

Microscopic domain
(molecules, atoms, etc.)

When teaching, secondary chemistry teachers are experienced in going from the macro-domain to the micro-domain and back to the macroscopic, using formulas, atomic icons and so on. For them, a formula as H_2O has several meanings and refers to e.g. the substance of water, a single molecule of water, one mole of water. The formula also contains stoichiometric information about water, in the macro-domain as well as in the micro domain. Teachers' mental switching between macro- and micro-aspects of science curriculum topics is conducted easily and almost automatically (Johnstone, 1993).
Secondary school students often experience difficulties in understanding chemistry topics at a macro-micro-symbolic interface. For them, the conceptual demands of shifting between the domains can be overwhelming. Their difficulties have been reported in several studies (e.g. Andersson, 1990; Benson et al., 1993; Driver et al., 1985; Griffiths and Preston, 1992). It appears that students are able to reason on both the macro- and the micro-level, but they are inclined to mix up these levels. For example, as De Vos and Verdonk (1987) and Lee et al. (1993) have indicated, many students seem to think that a molecule or an atom has the macro properties characterizing the related substance, e.g. the water molecule is wet and the carbon atom is black. Students also appear to experience difficulties in understanding symbolic representations. For example, as Ben-Zwi et al. (1988) have shown, students are inclined to interpret formulas of compounds in an additive manner, e.g. H_2O means that the water molecule consists of two distinguishable fragments, viz. H_2 and O. In addition, Friedel and Mahoney (1992) have pointed out that students experience difficulties in relating the subscripts in chemical formulas to the appropriate number of atoms. Regarding chemical reaction equations, Yarroch (1985) has indicated that students are inclined to violate the balancing rule which states that subscripts are not to be changed while balancing equations. And Garforth et al. (1976) have reported a number of students'

difficulties in understanding ionic equations, e.g. a lack of understanding of the meaning of 'spectator ions'.
As learning to link macroscopic phenomena with microscopic particles and symbolic representations constitutes one of the most important objectives of science education, prospective chemistry teachers need to develop PCK in this domain. We assume that these teachers, being educated as chemists, have developed a habit of discussing these links in a flexible and implicit manner, thus possibly creating confusion among their students. As a consequence, prospective chemistry teachers may encounter difficulties when teaching topics at a macro-micro-symbolic interface. This may cause development of their PCC as part of development of their PCK.

3. Research questions

Fuller and Bown (1975) have also indicated that the (first) stage of self concern is preceded by a stage of pre-teaching concerns. In that stage, prospective teachers are concerned about students, because in fact they still identify with students. They have not experienced the realities of the teaching role. From Fuller and Bown's model, it may be expected that before teaching chemistry topics at a macro-micro-symbolic interface, prospective teachers have PCC, which can be categorised as student concerns. However, from the model, the pedagogical content of these concerns cannot be derived and research on PCC has hardly been carried out. For that reason, the following research question is formulated:
* *What are the major pedagogical content concerns of prospective chemistry teachers before teaching chemistry topics at a macro-micro-symbolic interface?*

From Fuller and Bown's model, it may also be expected that after teaching curriculum topics, prospective teachers also express other types of concerns. However, again, little is known about the pedagogical content of these concerns. For that reason, a second research question is formulated as follows:
* *What are the major pedagogical content concerns of prospective chemistry teachers after teaching chemistry topics at a macro-micro-symbolic interface?*

Science teacher education should pay attention to the concerns of prospective teachers, also to their PCC. From this perspective, the answers to both research questions can contribute to a better understanding of the development of prospective chemistry teachers' PCC. Besides, the answers can contribute to providing a sound base for improving chemistry teacher education.

4. Research method

During the autumn of 1997, a research project was initiated focusing on Dutch prospective teachers' concerns about teaching chemistry topics at a macro-micro-symbolic interface. Given the exploratory nature of this study, a naturalistic case-study design was chosen, mainly involving the use of interviews to collect data. A phenomenological perspective on the analysis of interview data (Cohen and Manion, 1994) was adopted.
During the research project, the authors of this article acted as researchers as well as qualified chemistry teacher educators of the prospective teachers involved.

The participants and their context

Eight prospective chemistry teachers (five females and three males; average age: 23) were involved in the project. All participants had a master degree in chemistry and were participating in a university teacher education course. This post-degree course (one year) consists of an integrated mixture of university lectures and workshops, and teaching activities at secondary schools. An extensive description of the Dutch university teacher-education is in Wubbels (1992).

The participants entered the project at the beginning of the third course month. During the two months preceding, they had attended lectures on teaching and learning, and workshops on preparing and evaluating chemistry lessons. Besides, they had done some teaching practice at schools, supervised by a mentor. That means, they had observed and discussed the mentor's lessons in the first weeks of the course. Next, they had begun to teach their own classes. During the two months, no specific attention was given to the meaning or use of the macro-micro-symbolic interface. In the third month, the prospective teachers were asked individually to choose a forthcoming topic from the chemistry curriculum in which the relationship between macroscopic phenomena, microscopic particles and symbolic representations is prominent

Three participants chose the topic of writing and balancing simple reaction equations, aimed at students of grade 9 (age 14-15). The focus was: linking the changing of substances with reordening of atoms and reaction equations. Five participants chose the topic of precipitation reactions, aimed at students of grade 10 (age 15-16). The focus was: linking precipitation phenomena with the dynamics of ions in solutions and reaction equations. Each prospective teacher taught the chosen topic at his/her practice teaching school, using the current textbook. Each of them taught the topic to one class numbering approximately 20 students.

Data collection

In the context of the project, the prospective teachers were interviewed individually by one of the authors before and after the first two lessons on the chosen topic. During the pre-lessons interview, they were invited to explain their lesson plans and relevant students' (pre)conceptions. They were also asked to express their expectations regarding the students' conceptual difficulties as well as their own difficulties in teaching the topic. During the post-lessons interview, they could report on their lesson experiences. They could also reflect on the reported conceptual difficulties of their students and their own teaching difficulties. The prospective teachers were assured that their responses would in no way affect the assessment of their teaching practice.

All the interviews were audiotaped. The lessons under consideration were also audiotaped (by the prospective teachers themselves). The interviews and classroom discussions were transcribed into protocols. The interview protocols served as the core data source for the study. The classroom protocols provided contextual information, just as the chemistry textbooks that were used.

Data analysis

The analysis of the data was performed following a phasewise procedure. In the first phase, the pre- and post-lessons interview protocols of each prospective teacher were independently and repeatedly read. The content was analyzed in

an iterative way by each of the authors, using the following main analysis categories: self PCC, task PCC and student PCC. Subsequently, within each category, statements were classified into subcategories. In the next phase, analysis results of the individuals were compared to identify common (sub)concerns. In this phase, researchers triangulation (Janesick, 1994) was applied by comparing and discussing interpretations of the authors of this paper. The validation of these interpretations was promoted by applying the constant comparative method (Denzin, 1994). This involved the comparison of the analysis of the interview protocols with other sources, viz. (a) the classroom protocols, especially the classroom discussions between students and the prospective teachers about students' conceptual difficulties, and (b) additional data, especially chemistry textbooks, to trace the possible origins of the prospective teachers' statements and classroom discussions.

5. Results of the study

5.1 Concerns before teaching

The pre-lesson interviews indicated that the prospective teachers had a rather vague image of the difficulties they might encounter in their lessons when teaching their topic. Many expressed their concerns in rather short statements. A summary of their pre-teaching PCC which emerged from the analysis of the pre-lesson interview is given in table 1. Concerns are only given if expressed by at least two prospective teachers each of whom had chosen a different curriculum topic to teach. A concise elaboration of the pre-teaching concerns follows.

Self PCC

One prospective teacher expressed statements of self PCC, but because of the chosen selection criterium, these will be left out of consideration.

Task PCC

How to teach heuristics for building up appropriate symbolic representations
Two prospective teachers wondered how to teach heuristics for building up appropriate symbolic representations. For example, in the case of balancing reaction equations, it was expected that students would balance the equations by using mathemathical procedures but without any interpretation of the equations from a macro-micro-perspective. This kind of expectation contributed to concerns about the best ways to help students improve their understanding of what they were doing when developing symbolic representations.

Student PCC

Students' difficulties in understanding the macro- and micro-meaning of reaction equations
Three prospective teachers expressed concerns about students' difficulties in understanding the macro- and micro-meaning of reaction equations. For example, some of them expected that students would not write down spectator ions in the precipitation reaction equations. For that reason the students would not have any idea which ions would be in the solution beside the precipitate.

Students' difficulties in understanding the macro- and micro-meaning of formulas
Two prospective teachers expressed concerns about students' difficulties in understanding the macro- and micro-meaning of formulas. For example, in the case of describing the composition of solutions of salts, it was expected that students would be inclined to write down wrong formulas. In particular, it was expected that students would be tying formulas together, e.g. noting $NaCl(aq)$ instead of noting $Na^{+}(aq) + Cl^{-}(aq)$.

Table 1. Summary of prospective teachers' pedagogical content concern (PCC)

Category of reported PCC	Number of prospective teachers (N = 8) expressing concerns before teaching	after teaching
Self PCC	(N = 0)	(N = 8)
* Too fast zig-zag reasoning	0	8
* Dominant orientation on micro-level	0	6
* Mixing up macro- and micro level	0	6
Task PCC	(N = 2)	(N = 7)
* How to teach heuristics for building up symbolic representations	2	4
* How to handle inapropriate symbolic representations in textbooks	0	4
Student PCC	(N = 3)	(N = 5)
* Difficulties in understanding the macro- and micro-meaning of reaction equations	3	5
* Difficulties in understanding the macro- and micro-meaning of formulas	2	5

5.2 Concerns after teaching

Before presenting the post-teaching PCC, it must be noticed from the classroom protocols, that the prospective teachers appeared to use more or less the same overall teaching strategy. Roughly speaking, they discussed the macro-micro-symbolic relationship by going through illustrative topic examples taken from the textbook, at the same time asking students several questions about the topic taught. In the case of teaching the topic of precipitation reactions, they alternated the discussions with some inquiry-oriented and verification type laboratory experiments, also taken from the textbook. Students had to answer textbook questions, working in small groups or on their own. The prospective teachers closely followed the textbook and to a large extent, the textbook sequencing of the sub-topics. The observed strategy can be characterized as the usual teaching approach.
After the lessons, the prospective teachers reported that they had experienced many more difficulties than they had expected beforehand. It appeared that they repeated the concerns mentioned before the teaching and reported a number of new concerns. Besides, they expressed their concerns in a much

more detailed way. A summary of their post-teaching PCC emerging from the analysis of the post-lesson interview is given in table 1. Again concerns are only given if expressed by at least two prospective teachers each of whom had chosen a different curriculum topic to teach. A concise elaboration of the post-teaching concerns follows.

Self PCC

Too fast zig-zag reasoning

All prospective teachers expressed concerns about their mental switching between the macroscopic, the microscopic and the symbolic level. They acknowledged that their zig-zag reasoning was fast and mainly unconcious as indicated by the following representative statement:

> "I see, it [precipitate] become white and I immediately think, a precipitate is formed from two ions. I do it automatically. Just because of that, because we do it automatically, while the students have to think, I believe it is useful to point out that (. . .) students experience difficulties in switching, while we do not . . . when something is at the micro-level and when something is at the macro-level. For students, that is confusing, I believe."

The prospective teachers had noticed that their students could often not follow their swift mental jumps from one level to another.

Dominant orientation on the micro-level

Six prospective teachers expressed concerns about their dominant orientation on the micro-level. They indicated they were inclined to reason spontaneously in terms of particles without any explicit reference to relevant observations of phenomena. This strong orientation on the micro-meaning of reactions occurred especially when carrying out experiments in the classroom. A representative statement follows:

> "Often (. . .) you start at once to talk in terms of models. Instead of letting them have a look first, ask them what they see, two clear solutions and a solid substance is forming. And from that go on to the explanations. You are inclined to dive immediately into the models. That happened in the case of [pouring together] copper sulfate solution and sodium hydroxide solution. Then again you start at once. What occurred? Yes, the copper ions go to the hydroxide ions and they form a precipitate. Instead of observing the phenomena first and then go to the models. You are inclined to go to the models immediately (. . .) For them in particularly, it becomes unclear "

The prospective teachers had experienced that this approach caused a lot of students to fail to understand new concepts and rules.

Mixing up the macro- and micro-level

Six prospective teachers expressed concerns about their mixing up of phenomena and accompanying explanations in terms of particles. They indicated omitting make a clear distinction between what had occurred and what might explain it. For example, statements consistent with the following were common:

> "I believe, you are very aware of mixing up these [levels]. The fact is, you have been doing it for years. So, you have to become aware of . . . what are the phenomena and when are you going to explain them. If you are mixing this up, the students will not understand you at all. (. . .) If you ramble on from one level to another, something about those phenomena at one time and at another something about the model, they get totally dizzy"

The prospective teachers had reported that their students became confused and, for that reason, experienced conceptual difficulties.

Task PCC

How to teach heuristics for building up appropriate symbolic representations
Half of the prospective teachers wondered how to teach heuristics for building up appropriate symbolic representations. In the case of balancing reactions, the prospective teachers had experienced that students were inclined to balance the equations in a mathematics context only, viz. by counting symbols without any interpretations of the symbols from a macro-micro-perspective. A clarifying statement follows:

> "In balancing those reaction equations (. . .), it could be that many students try to learn an algorithm in order to balance it. For example, [they reason] I am lacking 'that', then I have to write down 'this' here, then it is correct. However, they should keep the situation at the back of their mind; what is the meaning of those abbreviations, and so on (. . .) Sometimes, something is written as: you take an Erlenmeyer flask, throw 'this' into it, and 'that' is already inside it (. . .) You catch them at grasping formulas and calculation tricks instead of imagining what is present and what happens and so on (. . .) Regarding the ammonia synthesis, [they reason] the following is not correct: N_2 and H_2 and NH_3; there is only one N, so it becomes N_3H_3 (. . .) You have to repeat it again and again and always explain in a different way how it works (. . .) yes, that is hard"

This kind of students' approach to build up symbolic representations caused difficulties for the prospective teachers in finding ways to help students improve their understanding.

In the case of the topic of precipitation reactions, the prospective teachers had experienced students were lacking a well-structured macro-micro-overview of the salt solutions and the precipitate to properly select and write down reaction equations. The prospective teachers wanted to help their students. For example, this is noted as follows:

> "In order to help, in the explications of those classroom experiments, I made the following drawings. I drew a test tube plus another test tube [noting ionic formulas in the tubes], arrow to the right, test tube including a precipitate [noting formulas in the tube]. So, they could imagine it (. . .) I was thinking about the best way in which they could get an overview"

The prospective teachers were looking for ways to help students to properly built up microscopic images of precipitation phenomena.

How to handle inappropriate symbolic representations in textbooks
Half of the prospective teachers were dissatisfied with some textbook prescriptions for writing down reaction equations. According to them, these prescriptions were not very appropriate. For example, prospective teachers were not satisfied with the textbook heuristic to write down a reaction equation by a step by step procedure. This is illustrated by the following statement:

> "You conduct a classroom experiment [from the textbook], with which you catch the students' attention, nice to see. Then, in my opinion, the textbook takes it very slowly. I immediately begin to write down a reaction equation. The textbook, however, begins by transforming the classroom experiment into a reaction scheme in words, subsequently transforming it into abbreviations, and after some sections, the formulas come. While, in my opinion, if you start early [to write reaction equations], although they need not be able to do it by themselves, they will less scared"

The prospective teachers wondered how to handle the prescriptions to write down reaction equations in the textbooks.

Another example is on textbook prescriptions to write down formulas of salts. The prospective teachers indicated that the textbooks contain salt formulas which are noted as e.g. $Na^+Cl^-(s)$ and $Pb^{2+}(I^-)_2(s)$. According to them, these

kind of formulas were misleading for students because of the presence of signs of charge in such formulas. A clarifying statement is:

> "Confusing, because, in that case, you have charged things in a solid substance and I actually try to teach them that a solid substance consists of charged things but the whole is neutral, otherwise it would not be a solid but an ion"

Moreover, the prospective teachers were afraid that, in the case of describing the dissolving of a salt as sodium chloride in water, the students would put the symbol 'aq' in the formula $Na^+Cl^-(s)$ itself, especially when the formula is written carelessly with much space between the ion symbols as Na^+ and Cl^-. Together with the noted symbol 's', the students' final formulas will be far from the generally accepted notation forms. The prospective teachers wondered how they could explain to the students that these kind of salt formulas in textbooks were misleading.

Student PCC

Students' difficulties in understanding the macro- and micro-meaning of reaction equations

Five prospective teachers expressed concerns about students' difficulties in understanding the macro- and micro-meaning of reaction equations. They noticed that students were inclined to interpret reaction equations in a microscopic context only. An illustrative statement is:

> "They do not see that a reaction equation does not only refer to molecules, but also to bigger amounts . . ."

In particular, the prospective teachers concerns regarded students' difficulties in understanding reaction equations including not only symbols refering to microscopic particles, but also including symbols refering to particles as well as to the accompanying substance(s). As an example, the prospective teachers mentioned the case of writing down and interpreting equations reflecting.the dissolving of salts in water. According to them, such equations should be noted as, e.g. $NaCl(s) \rightarrow Na^+(aq) + Cl^-(aq)$. just as they said that precipitation reaction equations should be noted as, e.g. $Pb^{2+}(aq) + 2I^-(aq) \rightarrow PbI_2(s)$. The prospective teachers considered formulas as $NaCl(s)$ and $PbI_2(s)$ as formulas which refer to substances and, for that reason, these formulas should not be noted as $Na^+Cl^-(s)$ and $Pb^{2+}(I^-)_2(s)$ in which $Na^+(aq)$, $Cl^-(aq)$, $Pb^{2+}(aq)$ and $I^-(aq)$ refer to ions and not to substances.

The prospective teachers reported two kinds of students' conceptual difficulties. In the case of dissolving processes, students wondered why they should actually write down signs of charge , because the formed solution is as neutral as the initial salt. In the case of precipitation processes, students wondered why it is not allowed to write down signs of charge, because the product is formed from ions. A representative example of the statements is given below:

> "They are confused. When do you write, yes or no, charges with substances, because, when they had a solid salt, I did not want to note the charges. If it is a solid, not. But if it is dissolved, it should be done (. . .) Nevertheless, for a number of students, that was confusing (. . .) you have to write down charges, they exist as free ions, in that case, it is charged, of course . . . it is charged. But why should you write that down . . . according to some students, that was somewhat of a contradiction (. . .) Most of the students, when I asked it, knew that a solution itself is obviously not charged. If you put your finger in it, nothing happens. If you touch a salt in a normal way, nothing happens too. But when should you add pluses and minuses. That was strange (. . .) Why should you write down $Pb^{2+}(aq)$ suddenly, why add that two plus?"

Students' difficulties in understanding the macro- and micro-meaning of formulas
Five prospective teachers expressed concerns about students' difficulties in understanding the macro- and micro-meaning of formulas. As an example, they mentioned the case of formulas used to refer to non-decomposable substances consisting of multi-atomic molecules. According to the prospective teachers, a substance such as oxygen should be represented by the formula O_2, while students think that this should be O. Such students' conceptions may cause learning difficulties. The following representative statement illustrates this point:

> "I asked an example of a liquid in which a gas was dissolved (. . .) I thought about an ammonia solution or something like that. However, a student said: water which contains dissolved oxygen . . ., yes, because fishes take oxygen from the water. Then, I kept asking and then it came, yes, H_2O for water (. . .) oxygen is O,. They do not think beyond, I am afraid"

Regarding the topic of precipitation reactions, the prospective teachers also indicated that students did not understand the difference between a notation as $Na^+(aq) + Cl^-(aq)$ and a notation as $NaCl(aq)$.

6. Discussion

The present study reveals the major concerns of prospective teachers as reported by them before and after teaching chemistry topics at a macro-micro-symbolic interface. Their concerns are classified as pedagogical content-related self concern, task concern and student concern. The pre-teaching PCC appears to consist of student PCC and some task PCC, while the post-teaching PCC not only consists of these concerns but also extends to more task PCC and to self PCC. Besides, for each of the three categories, the number of prospective teachers that express PCC is increased. These results reflect the impact of teaching practice on the prospective teachers' knowledge base (c.f. Lederman et al., 1994). These outcomes are also in line with the concerns model of Fuller and Bown (1997). Before teaching, there is mainly student PCC. After teaching, self PCC is the major concern, student PCC is the minor concern and task PCC is in between.

Regarding the *self* PCC, the results indicate that this type of concern is lacking before teaching. After teaching, however, (nearly) all prospective teachers express self PPC, especially concerns about too fast zig-zag reasoning, dominant orientation on the micro-level and mixing up the macro- and micro-level. This development reflects an emerging awareness of their own ways of mental switching between the macroscopic and the microscopic level, which can hinder the learning processes of students. The absence of this awareness before teaching can be explained by looking at the prospective teachers' subject matter expertise. To them, switching between a macro-level, a micro-level and a symbolic level has become second nature. Their knowledge and skills have accumulated during a long period of learning (school) chemistry. To be conscious of novices' conceptions is not something that comes easily to experts (De Jong et al., 1995).

Regarding the *task* PCC, the results point out that many more prospective teachers espress this type of concern after teaching than before. The reported development reflects growing concerns about teaching heuristics for building up symbolic representations and handling inadequate symbolic representations

in textbooks. The last-mentioned subconcern is interesting, because, as Yager (1983) has pointed out, textbooks are seen by (prospective) teachers as very important sources of information, which have a great influence on their knowledge base and teaching decisions. The results of the present study show that, before teaching, the prospective teachers are not really concerned about the quality of the content of their textbook. However, after teaching, they become aware of some shortcomings in the textbooks, such as the prescribed way of writing salt formulas as e.g. $Na^{+}Cl^{-}(s)$. This kind of writing is confusing because the symbol 's' refers to the macro-level, while the ion symbols refer to the micro-level, so, a confusing mixture of reality and model are present in such formulas. The initial lack of 'textbook concern' can be explained by the hindering effect of their own subject matter expertise, just as in the case of the absence of the pre-teaching self PCC.

Regarding the *student PCC*, the results show that this type of concern is already expressed before teaching. This can be caused by the preceding teaching experiences of the prospective teachers. During the two month preceding, they have already taught some other chemistry topics, partly to other classes, and they may have observed some students' difficulties in understanding formulas and equations. The total absence of self PCC and the partial absence of task PCC before teaching can be considered as indications that earlier the prospective teachers have hardly paid atttention to teaching the macro- and micro meaning of formulas and equations.

The study has the character of an exploration of the rather unknown field of prospective teachers' knowledge of difficulties in teaching specific science topics. It is evident that the value of the results is limited by the fact that the reported concerns have only been investigated in the context of a small number of specific topics. Nevertheless, by choosing the general issue of the relationship between phenomena, particles and symbolic representations, it appears to be possible to collect important data about pedagogical content concerns of prospective teachers. For that reason, research into these kind of concerns about issues other than the present issue should be initiated.

7. Implications for science teacher education

Science teacher education should pay attention to the concerns of prospective teachers, and also to their PCC. Based on the data presented here, it can be stated that the volume of PCC that prospective science teachers express, can increase rapidly after a couple of lessons on a new curriculum topic or issue. This has important implications for the design of science teacher preparation courses. This design should be structured in such a way that prospective science teachers' PCC is taken into account as much as possible. A promising design can include the following five stages:

a) Clarifying existing PCC
During this stage, the prospective teachers start to describe and discuss their own difficulties in understanding a specific curriculum topic or issue. Subsequently, they analyse some literature or some classroom protocols with respect to relevant students' difficulties in understanding. They discuss the results of their analyses and compare the students conceptual difficulties with their own conceptions.

b) From these concerns to teaching intentions
During this stage, the prospective teachers analyse relevant parts of current science textbooks and discuss the quality and usefulness of their content. Subsequently, they draw up intentions for the teaching of a specific topic in their own classes.

c) From these intentions to teaching expèriences,
At this stage, the prospective teachers prepare lessons and teach these lessons at school.

d) From these experiences to new PCC
The prospective teachers reflect on their teaching and the PCC that has emerged.

e) [Back to step b]
The results of the reflections on the new PCC can function as a starting point for new intentions to teach.

This cyclical model can function as a well-founded basis for the construction of new courses that take prospective teachers' PCC into account. By taking such courses, prospective science teachers can improve their pedagogical content knowledge. In order to confirm these expectation, further research in the field of science teachers' knowledge bases should be initiated.

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